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# Statistical Analysis of Mining Waste Sample Data

Meridian Research, Inc., Silver Spring, MD

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# STATISTICAL ANALYSIS OF MINING WASTE SAMPLE DATA

FINAL REPORT

Submitted by:

Meridian Research, Inc.
818 Roeder Road
Silver Spring, Maryland 20910

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818 Roeder Road
Silver Spring, MD 20910

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**16. Abstract (Limit: 200 words)**

This report is derived from analyses of data on 582 mining waste samples collected at 99 mines. One set of analyses compares sample data with various EPA standards for hazard, drinking water, and ambient water. The other set of analysis compares metal concentrations in raw samples (total analyses), acetic acid extracts (Following Standard EPA(EP (Extraction Procedure), and distilled water extracts (Following a Modified EP). The analyses demonstrated that some standards are below the demonstrated that some standards are below the detectable limits for analytic tests used in the mining study and confirmed that acetic acid extraction is a more aggressive leaching technique for metals and anions, than distrilled water extraction. However, regression analyses showed few correlations between metal content of solid mining waste samples and concentrations in extracts. There was a linear relationship between lead content in raw samples versus acetic acid extracts.

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# STATISTICAL ANALYSIS OF MINING WASTE SAMPLE DATA

## 1.0 INTRODUCTION

The Environmental Protection Agency's Report to Congress entitled Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale included results of mining waste samples that were evaluated for the RCRA Subtitle C hazardous waste characteristics of corrosivity and EP toxicity and for several other potentially hazardous characteristics (cyanide content, radioactivity, asbestos content, and acid formation potential). The majority of the mining waste sample results used in the Report to Congress were taken from the following contractor reports prepared for the Environmental Protection Agency:

ERCO/A Division of ENESCO. 1984. Mining Waste Study: Draft Data Report Prepared for the Office of Solid Waste, U.S. Environmental Protection Agency under Contract No. 68-01-6467. Cambridge, MA: ERCO/A Division of ENESCO.

Harty, David M., and Terlecky, Michael P. 1982. Characterization of Wastewater and Solid Wastes Generated in Selected Ore Mining Subcategories (Sb, Hg, Al, V, W, Ni, Ti). Report prepared for the Effluent Guidelines Division, U.S. Environmental Protection Agency, by Frontier Technical Associates Inc. Contract No. 68-01-5163. Buffalo, NY: Frontier Technical Associates, Inc.

PEDCo Environmental, Inc. Evaluation of Management Practices for Mine Solid Waste Storage, Disposal, and Treatment. 3 Vols. Prepared for the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency. Contract No. 68-03-2900. Cincinnati, OH: PEDCo Environmental, Inc.

These reports contain the results of analyses conducted to measure the concentration of various elements, anions, radionuclides, and other parameters in raw mining waste samples and acetic acid extracts of these samples. The PEDCo report also contains results of analyses conducted on distilled water extracts of these samples. The results for cyanide presented in these reports were supplemented by additional data supplied by PEDCo Environmental Inc. to the Office of Solid Waste in 1984.

These reports presented many more mining waste sampling results than were necessary to evaluate these wastes for the RCRA Subtitle C hazardous waste characteristics of corrosivity and EP toxicity and the other potentially hazardous characteristics of cyanide, radioactivity, asbestos, and acid formation potential. This report presents an analysis of some of the data not used in the Report to Congress to aid in the Agency's determination of the hazard potential of mining and beneficiation wastes. In order to support the analyses necessary for the Mining Waste Report to Congress, Meridian Research, Inc. compiled the data from the above-named sources into an automated data base. The data base was subsequently augmented to support the analyses presented in this report.

Currently, the data base contains analytical results for 582 mining wastes samples taken from 99 mines. Analytical results from raw samples, acetic acid extracts, and distilled water extracts are included in the data base. In addition, samples are classified as being mine waste, tailings, or from a leach operation.

This report presents results for two types of analyses conducted by Meridian. In Section 2.0 of this report, Meridian presents the results of a comparative analysis between the mining waste sample data and a variety of EPA standards and criteria for hazardous waste, drinking water, and water quality. The comparative analysis expands upon the analysis of the mining waste data presented in the Report to Congress. Meridian also examined the relationships among the analytical results for raw samples, acid extract samples, and distilled water samples analyzed for EP-toxic metals. These relationships were analyzed using linear regressions and are discussed in Section 3.0. The detailed results of the regression analysis are presented in Appendices A and B.

## 2.0 COMPARATIVE ANALYSIS OF MINING WASTE DATA WITH VARIOUS EPA STANDARDS AND CRITERIA

In the Mining Waste Report to Congress, the potential environmental hazard posed by mining waste was assessed by comparing the mining waste sample data to the hazardous waste criteria established under RCRA Subtitle C (40 CFR 261.20-24), as well as to other potentially hazardous characteristics. A number of other EPA standards and criteria exist that can serve as benchmarks to aid in assessing the hazard potential of mining waste. Meridian identified several EPA standards and criteria that contain allowable or suggested contaminant limits for some of the parameters contained in the mining waste data base. These standards and criteria include:

- Prohibitions on the land disposal of liquid hazardous wastes specified in the 1984 RCRA Amendments
- National Primary Drinking Water Standards (40 CFR 141) promulgated under Section 1412 of the Safe Drinking Water Act.
- Secondary Drinking Water Standards (40 CFR 143), which, unlike the primary standards, are only advisory at the Federal level. These standards were also promulgated under Section 1412 of the Safe Drinking Water Act.
- Ambient water quality criteria for the protection of freshwater aquatic life (various Federal Register notices in 1985 and 1986) and human health (45 FR 79318, November 28, 1980) published under the aegis of Section 383 of the Clean Water Act.

Table 1 shows the mining waste parameters that were considered in the Report to Congress and that are considered in this analysis. The standards and criteria upon which this analysis is based are summarized in Table 2 and described briefly below.

### 2.1 DESCRIPTION OF EPA STANDARDS AND CRITERIA USED

#### 2.1.1 RCRA Amendments

The 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA) prohibited all methods of land disposal (except deep

Table 1. Mining Waste Parameters Measured by EPA Contractors

| Parameter[a] | Considered in Report to Congress | Considered in This Report |
|---|---|---|
| **Metals** | | |
| Ag Silver | Yes | Yes |
| As Arsenic | Yes | Yes |
| Ba Barium | Yes | Yes |
| Be Beryllium | No | Yes |
| Ca Calcium | No | No |
| Cd Cadmium | Yes | Yes |
| Cr Chromium | Yes | Yes |
| Ca Copper | No | Yes |
| Fe Iron | No | Yes |
| Hg Mercury | Yes | Yes |
| K Potassium | No | No |
| Mg Magnesium | No | No |
| Mn Manganese | No | Yes |
| Mo Molybdenum | No | No |
| Na Sodium | No | No |
| Ni Nickel | No | Yes |
| Pb Lead | Yes | Yes |
| Th Thallium | No | Yes |
| V Vanadium | No | No |
| Zn Zinc | No | Yes |
| **Anions and Others** | | |
| PH pH | Yes | Yes |
| ALK Alkalinity | No | No |
| ACY Acidity | No | No |
| COND Conductivity | No | No |
| TEMP Temperature | No | No |
| SSOL Settleable Solids | No | No |
| $NH_3$ Ammonia | No | Yes |
| $NO_3$ Nitrate | No | Yes |
| F Fluoride | No | Yes |
| TP Total Phosphorus | No | No |
| $SO_4$ Sulfate | No | Yes |
| TOC Total Organic Carbon | No | No |
| TSS Total Suspended Solids | No | No |
| TDS Total Dissolved Solids | No | Yes |
| SAR Sodium Adsorption Ratio | No | No |
| TURB Turbidity | No | Yes |

Source: Meridian Research, Inc.

[a] Excludes radionuclides.

Table 2. Hazardous Waste and Water Quality Standards (in mg/l) Used to Analyze Mining Waste Sample Results

| Mining Waste Parameters Measured | Standards Specifying Limits for These Parameters | | | | | |
|---|---|---|---|---|---|---|
| | Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations | National Secondary Drinking Water Regulations | Ambient Water Quality Criteria for Human Health | Ambient Water Quality Criteria for Freshwater Aquatic Life |
| Ag (Silver) | | 5 | 0.05 | | 0.050 | |
| As (Arsenic) | 500 | 5 | 0.05 | | 0.0000022 | 0.19[b] |
| Ba (Barium) | | 100 | 1.00 | | | |
| Be (Beryllium) | | | | | 0.0000037 | |
| Cd (Cadmium) | 100 | 1 | 0.01 | | 0.010 | 0.0011[c] |
| Cr (Chromium) | 500 (VI) | 5 | 0.05 | | 0.050 (VI) | 0.011 (VI)[b] |
| Cu (Copper) | | | | 1.0 | 1.0 | 0.012[c] |
| Fe (Iron) | | | | 0.3 | | |
| Hg (Mercury) | 20 | 0.2 | 0.002 | | 0.000144 | 0.000012[b] |
| Mn (Manganese) | | | | 0.05 | | |
| Ni (Nickel) | 134 | | | | 0.0134 | 0.16[b] |
| Pb (Lead) | 500 | 5 | 0.05 | | 0.050 | 0.0032[b] |
| Se (Selenium) | 100 | 1 | 0.01 | | 0.010 | 0.01[b] |
| Tl (Thallium) | 130 | | | | | |
| Zn (Zinc) | | | | | 5.0 | |
| Cyanides | 1,000 | | | 5.0 | 0.20 | 0.0052[b] |
| $NH_3$ (Ammonia)[a] | | | | | | 0.0019(pH=6.5)[e] |
| $NO_3$ (Nitrate) | | | | | | 0.035(pH=8)[e] |
| F (Fluoride) | | | 10.0 | | | |
| $SO_4$ (Sulfate) | | | 4.0 | | | |
| pH[d] | | | | 2.0 | | |
| TDS (Total dissolved solids)[a] | <2 | ≤2 or ≥12.5 | | 250 | | |
| TURB (Turbidity)[a] | | | | 6.5 - 8.5 | | |
| | | | | 500 | | |
| | | | 1 TU (turbidity unit)[d] | | | |

Source: Meridian Research, Inc.

[a] Measured only in liquids.

[b] Four-day average concentration that should not exceed stated level more than once every three years on the average.

[c] Four-day average concentration (assuming a water hardness of 100 mg/l as $CaCO_3$) that does not exceed stated level more than once every three years on the average.

[d] (1) One turbidity unit (TU), as determined by a monthly average pursuant to §141.22, except that five or fewer turbidity units may be allowed if the supplier of water can demonstrate to the State that the higher turbidity does not create any of the following circumstances:

(a) Interference with disinfection;
(b) Prevention of maintenance of an effective disinfectant agent throughout the distribution system; or
(c) Interference with microbiological determinations.

(2) Five turbidity units based on an average for two consecutive days pursuant to §141.22.

[e] Standard for water at 25°C where Salmonid-sensitive species are present.

well injection) of the so-called "California list" of hazardous wastes unless EPA determines that the prohibition is not required to protect human health and the environment. In making this determination, the Administrator of EPA must take into account the long-term uncertainties associated with land disposal; the goal of managing hazardous waste in an appropriate manner; and the persistence, toxicity, mobility, and propensity of such hazardous wastes (and their constituents) to bioaccumulate. The "California list" of hazardous wastes includes liquid hazardous wastes and sludges containing specified concentrations of cyanide, heavy metals or arsenic, highly acidic liquids, liquids containing 50 or more parts per million of polychlorinated biphenyls (PCBs), and halogenated organic compounds in total concentrations of 1000 mg/kg or greater. The limits for land disposal of wastes containing constituents that are relevant to the mining waste sample data are listed in Table 2.

### 2.1.2 RCRA Subtitle C Characteristics of Hazardous Waste

The RCRA Subtitle C characteristics for identifying wastes as being hazardous include the following:

- Ignitability. The waste poses a fire hazard during routine management.
- Corrosivity. The waste has the ability to corrode standard containers or to dissolve toxic components of other wastes.
- Reactivity. The waste has a tendency to explode under normal management conditions, to react violently when mixed with water, or to generate toxic gases.
- EP Toxicity. The waste exhibits the presence of one or more specified toxic materials at levels greater than those designated in the Agency's regulations when it is analyzed by a specific "extraction procedure."

EPA's Report to Congress contained an analysis of the mining waste data set for the characteristics of corrosivity and EP toxicity. A waste is

considered corrosive and therefore hazardous if it is a liquid and has a pH less than or equal to 2 or greater than or equal to 12.5, as determined by a pH meter. EPA chose pH as a "barometer of corrosivity, because wastes exhibiting low or high pH can cause harm to human tissue, promote the migration of toxic contaminants from other wastes, and harm aquatic life" (45 FR 33109, May 19, 1980).

A solid waste is defined as EP toxic and therefore hazardous if, using the test methods described in 40 CFR Part 261 (Appendix II), an acetic acid extract from a representative sample of waste contains certain metals at a concentration greater than or equal to 100 times the maximum contaminant levels for these metals as established by EPA's National Primary Drinking Water Standards. The limits set by RCRA Subtitle C characteristics for corrosivity and EP toxicity (for metals) are shown in Table 2.

### 2.1.3 Primary and Secondary Drinking Water Standards

Drinking water standards, mandated under Section 1412 of the Safe Drinking Water Act (SDWA) (PL 93-523)(42 USC 300f et seq.), apply to public water systems, which are defined as those systems piping water for consumption by 25 or more people or those systems having at least 15 service connections. Under this act, the EPA sets both primary and secondary water standards.

EPA's National Primary Drinking Water Standards (NPDWS) set limits for contaminants that may affect health. The primary water rules specify allowable Maximum Contaminant Levels (MCLs) as shown in Table 2.

Regulations for the implementation and enforcement of the National Primary Drinking Water Regulations are contained in 40 CFR 141. States are required to monitor and measure the amounts of specified contaminants in public water supplies and periodically report the results to the EPA. Local

governments and private water companies that supply water to the public must test water quality to ensure that specified contaminants do not exceed Federal limits. Suppliers of water must keep records of water quality, notify consumers if any MCL is being exceeded, and act promptly to correct any rule violation.

EPA's National Secondary Drinking Water Standards (NSDWS) apply to drinking water contaminants that primarily affect the aesthetic qualities relating to the public acceptance of drinking water. These standards are only advisory, are not Federally enforceable, and are intended as guidelines for States. The secondary MCLs for public water systems include those contaminants listed in Table 2.

### 2.1.4 Water Quality Criteria

Criteria for water quality are set by EPA to indicate the levels of specific pollutants that ambient water can contain and still be suitable for certain purposes. Once these criteria are set, States use them to establish water quality standards and to determine the discharge limits for individual National Pollutant Discharge Elimination System (NPDES) permits. The Federal Government uses the criteria to set general effluent limitation guidelines for various industrial and municipal pollution sources.

Section 304(a)(1) of the CWA requires EPA to publish and periodically update ambient water quality criteria in order to reflect the latest scientific knowledge on the identifiable effects of pollutants on public health and welfare, aquatic life, and recreation. The ambient water quality criteria for human health (Table 2) were originally published on November 28, 1980 (45 FR 79318). The freshwater aquatic life criteria cited in Table 2 for arsenic, cadmium, chromium (VI), copper, lead, mercury, nickel, and selenium

replace the criteria previously published in 1980. The freshwater aquatic life criteria for ammonia replace criteria originally published in 1976.

## 2.2 RESULTS OF COMPARATIVE ANALYSIS

Table 3 shows, for acid extraction of metals and anions, the number of mine waste, tailings, or leachate samples that exceed each of the standards or criteria used in the comparison. The table also shows the total number of samples that were analyzed for each of the parameters under consideration (not all samples were chemically analyzed for every parameter). The results of the analysis conducted on distilled water extracts of mining waste samples appear in Table 4. In order to provide results comparable to the analysis of EP-toxic metals in the Report to Congress, data contained in the PEDCo report for liquid samples were excluded from consideration. In addition, 35 mining waste samples taken from inactive mines were excluded.

As shown in Table 3, there are fewer acid extracts of tailings samples than mine waste samples for all parameters measured. However, for most of the parameters, a greater number of tailings samples than mine waste samples exceed standards for primary and secondary drinking water and ambient water quality criteria for human health and aquatic life. For distilled water extracts of samples, this was only true for most parameters measured when they were compared to the primary and secondary drinking water standards (Table 4). These results are not surprising given that tailings are generated from beneficiation of enriched product rather than from extraction of raw ore.

For a few metals, 100 percent of all acid and water extracts exceed certain standards; this was noted when samples analyzed for arsenic or beryllium were compared to respective ambient water quality criteria standards for human health, or when samples analyzed for mercury were compared to the

Table 3. Number of Acetic Acid Extract Samples that Exceed Specified Standard, by Parameter Measured and Type of Waste

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples[a] | Standards Specifying Limits for These Parameters: Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations (1X) | National Primary Drinking Water Regulations (100X) | National Secondary Drinking Water Regulations (1X) | National Secondary Drinking Water Regulations (100X) | Ambient Water Quality Criteria for Human Health (1X) | Ambient Water Quality Criteria for Human Health (100X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (1X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (100X) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **As (Arsenic)** | | | | | | | | | | | |
| Mine Waste | 206 | 0 | 0 | 13 | 0 | NA | NA | 206 | 194 | 0 | 0 |
| Tailings | 189 | 0 | 0 | 25 | 0 | NA | NA | 189 | 188 | 10 | 0 |
| Leachate | 18 | 0 | 1 | 6 | 1 | NA | NA | 18 | 18 | 5 | 0 |
| **Ag (Silver)** | | | | | | | | | | | |
| Mine Waste | 203 | NA | 0 | 3 | 0 | NA | NA | 3 | 0 | NA | NA |
| Tailings | 189 | NA | 0 | 11 | 0 | NA | NA | 11 | 0 | NA | NA |
| Leachate | 18 | NA | 0 | 3 | 0 | NA | NA | 3 | 0 | NA | NA |
| **Ba (Barium)** | | | | | | | | | | | |
| Mine Waste | 203 | NA | 0 | 16 | 0 | NA | NA | NA | NA | NA | NA |
| Tailings | 189 | NA | 0 | 14 | 0 | NA | NA | NA | NA | NA | NA |
| Leachate | 18 | NA | 0 | 2 | 0 | NA | NA | NA | NA | NA | NA |
| **Be (Beryllium)** | | | | | | | | | | | |
| Mine Waste | 203 | NA | NA | NA | NA | NA | NA | 203 | 138 | NA | NA |
| Tailings | 189 | NA | NA | NA | NA | NA | NA | 189 | 141 | NA | NA |
| Leachate | 18 | NA | NA | NA | NA | NA | NA | 18 | 14 | NA | NA |
| **Cd (Cadmium)** | | | | | | | | | | | |
| Mine Waste | 203 | 0 | 0 | 49 | 0 | NA | NA | 49 | 0 | 202 | 3 |
| Tailings | 188 | 0 | 0 | 68 | 0 | NA | NA | 68 | 0 | 187 | 11 |
| Leachate | 18 | 0 | 1 | 10 | 1 | NA | NA | 10 | 1 | 18 | 3 |
| **Cr (Chromium)** | | | | | | | | | | | |
| Mine Waste | 203 | 0 | 0 | 63 | 0 | NA | NA | 63 | 0 | 126 | 0 |
| Tailings | 189 | 0 | 0 | 78 | 0 | NA | NA | 78 | 0 | 123 | 1 |
| Leachate | 18 | 0 | 0 | 11 | 0 | NA | NA | 11 | 0 | 11 | 3 |
| **Cu (Copper)** | | | | | | | | | | | |
| Mine Waste | 203 | NA | NA | NA | NA | 11 | 0 | 11 | 0 | 109 | 11 |
| Tailings | 189 | NA | NA | NA | NA | 28 | 1 | 28 | 1 | 136 | 24 |
| Leachate | 18 | NA | NA | NA | NA | 12 | 3 | 12 | 3 | 17 | 12 |

Table 3. Number of Acetic Acid Extract Samples that Exceed Specified Standard, by Parameter Measured and Type of Waste (continued)

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples[a] | Standards Specifying Limits for These Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations (1X) | (100X) | National Secondary Drinking Water Regulations (1X) | (100X) | Ambient Water Quality Criteria for Human Health (1X) | (100X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (1X) | (100X) |
| **Fe (Iron)** | | | | | | | | | | | |
| Mine Waste | 203 | NA | NA | NA | NA | 49 | 1 | NA | NA | NA | NA |
| Tailings | 189 | NA | NA | NA | NA | 55 | 3 | NA | NA | NA | NA |
| Leachate | 18 | NA | NA | NA | NA | 7 | 5 | NA | NA | NA | NA |
| **Hg (Mercury)** | | | | | | | | | | | |
| Mine Waste | 205 | 0 | 0 | 20 | 0 | NA | NA | 184 | 8 | 205 | 24 |
| Tailings | 187 | 0 | 1 | 18 | 1 | NA | NA | 182 | 12 | 187 | 23 |
| Leachate | 18 | 0 | 0 | 4 | 0 | NA | NA | 18 | 3 | 18 | 4 |
| **Mn (Manganese)** | | | | | | | | | | | |
| Mine Waste | 203 | NA | NA | NA | NA | 174 | 35 | NA | NA | NA | NA |
| Tailings | 189 | NA | NA | NA | NA | 169 | 52 | NA | NA | NA | NA |
| Leachate | 18 | NA | NA | NA | NA | 14 | 8 | NA | NA | NA | NA |
| **Ni (Nickel)** | | | | | | | | | | | |
| Mine Waste | 203 | 0 | NA | NA | NA | NA | NA | 185 | 1 | 43 | 0 |
| Tailings | 189 | 0 | NA | NA | NA | NA | NA | 186 | 5 | 71 | 0 |
| Leachate | 18 | 0 | NA | NA | NA | NA | NA | 18 | 4 | 10 | 0 |
| **Pb (Lead)** | | | | | | | | | | | |
| Mine Waste | 203 | 0 | 6 | 158 | 6 | NA | NA | 158 | 6 | 203 | 13 |
| Tailings | 189 | 0 | 13 | 135 | 13 | NA | NA | 135 | 13 | 189 | 25 |
| Leachate | 18 | 0 | 0 | 10 | 0 | NA | NA | 10 | 0 | 18 | 1 |
| **Se (Selenium)** | | | | | | | | | | | |
| Mine Waste | 206 | 0 | 1 | 82 | 1 | NA | NA | 82 | 1 | 82 | 1 |
| Tailings | 189 | 0 | 0 | 97 | 0 | NA | NA | 97 | 0 | 97 | 0 |
| Leachate | 18 | 0 | 1 | 11 | 1 | NA | NA | 11 | 1 | 11 | 1 |
| **Tl (Thallium)** | | | | | | | | | | | |
| Mine Waste | 203 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Tailings | 189 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Leachate | 18 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |

Table 3. Number of Acetic Acid Extract Samples that Exceed Specified Standard, by Parameter Measured and Type of Waste (continued)

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples[a] | Standards Specifying Limits for These Parameters: Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations (1X) | National Primary Drinking Water Regulations (100X) | National Secondary Drinking Water Regulations (1X) | National Secondary Drinking Water Regulations (100X) | Ambient Water Quality Criteria for Human Health (1X) | Ambient Water Quality Criteria for Human Health (100X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (1X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (100X) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Zn (Zinc) | | | | | | | | | | | |
| Mine Waste | 203 | NA | NA | NA | NA | 9 | 0 | 9 | 0 | NA | NA |
| Tailings | 188 | NA | NA | NA | NA | 24 | 0 | 24 | 0 | NA | NA |
| Leachate | 18 | NA | NA | NA | NA | 5 | 1 | 5 | 1 | NA | NA |
| $NO_3$(Nitrate) | | | | | | | | | | | |
| Mine Waste | 185 | NA | NA | 1 | 0 | NA | NA | NA | NA | NA | NA |
| Tailings | 158 | NA | NA | 6 | 0 | NA | NA | NA | NA | NA | NA |
| Leachate | 17 | NA | NA | 2 | 0 | NA | NA | NA | NA | NA | NA |
| F (Fluoride) | | | | | | | | | | | |
| Mine Waste | 48 | NA | NA | 2 | 0 | 3 | 0 | NA | NA | NA | NA |
| Tailings | 54 | NA | NA | 8 | 0 | 14 | 2 | NA | NA | NA | NA |
| Leachate | 9 | NA | NA | 1 | 0 | 1 | 0 | NA | NA | NA | NA |
| $SO_4$(Sulfate) | | | | | | | | | | | |
| Mine Waste | 184 | NA | NA | NA | NA | 17 | 0 | NA | NA | NA | NA |
| Tailings | 156 | NA | NA | NA | NA | 39 | 1 | NA | NA | NA | NA |
| Leachate | 17 | NA | NA | NA | NA | 9 | 3 | NA | NA | NA | NA |

Source: Meridian Research, Inc.

NA = Not Applicable.

[a] Excludes PEDCo liquid samples.

Table 4. Number of Distilled Water Extract Samples that Exceed Specified Standard, by Parameter Measured and Waste Type

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples[a] | Standards Specifying Limits for These Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations | | National Secondary Drinking Water Regulations | | Ambient Water Quality Criteria for Human Health | | Ambient Water Quality Criteria for Freshwater Aquatic Life | |
| | | | | (1X) | (100X) | (1X) | (100X) | (1X) | (100X) | (1X) | (100X) |
| As (Arsenic) | | | | | | | | | | | |
| Mine Waste | 112 | 0 | 0 | 1 | 0 | NA | NA | 112 | 104 | 1 | 0 |
| Tailings | 71 | 0 | 0 | 3 | 0 | NA | NA | 71 | 70 | 1 | 0 |
| Leachate | 7 | 0 | 0 | 1 | 0 | NA | NA | 7 | 7 | 0 | 0 |
| Ag (Silver) | | | | | | | | | | | |
| Mine Waste | 110 | NA | 0 | 3 | 0 | NA | NA | 3 | 0 | NA | NA |
| Tailings | 71 | NA | 0 | 3 | 0 | NA | NA | 3 | 0 | NA | NA |
| Leachate | 7 | NA | 0 | 0 | 0 | NA | NA | 0 | 0 | NA | NA |
| Ba (Barium) | | | | | | | | | | | |
| Mine Waste | 110 | NA | 0 | 3 | 0 | NA | NA | NA | NA | NA | NA |
| Tailings | 71 | NA | 0 | 0 | 0 | NA | NA | NA | NA | NA | NA |
| Leachate | 7 | NA | 0 | 0 | 0 | NA | NA | NA | NA | NA | NA |
| Be (Beryllium) | | | | | | | | | | | |
| Mine Waste | 110 | NA | NA | NA | NA | NA | NA | 110 | 72 | NA | NA |
| Tailings | 71 | NA | NA | NA | NA | NA | NA | 71 | 49 | NA | NA |
| Leachate | 7 | NA | NA | NA | NA | NA | NA | 7 | 4 | NA | NA |
| Cd (Cadmium) | | | | | | | | | | | |
| Mine Waste | 110 | 0 | 0 | 10 | 0 | NA | NA | 10 | 0 | 109 | 1 |
| Tailings | 71 | 0 | 0 | 10 | 0 | NA | NA | 10 | 0 | 71 | 0 |
| Leachate | 7 | 0 | 0 | 4 | 0 | NA | NA | 4 | 0 | 6 | 0 |
| Cr (Chromium) | | | | | | | | | | | |
| Mine Waste | 109 | 0 | 0 | 2 | 0 | NA | NA | 2 | 0 | 52 | 0 |
| Tailings | 71 | 0 | 0 | 3 | 0 | NA | NA | 3 | 0 | 34 | 0 |
| Leachate | 7 | 0 | 0 | 2 | 0 | NA | NA | 2 | 0 | 4 | 0 |
| Cu (Copper) | | | | | | | | | | | |
| Mine Waste | 110 | NA | NA | NA | NA | 3 | 0 | 3 | 0 | 21 | 3 |
| Tailings | 71 | NA | NA | NA | NA | 6 | 1 | 6 | 1 | 19 | 6 |
| Leachate | 7 | NA | NA | NA | NA | 5 | 0 | 5 | 0 | 6 | 4 |

Table 4. Number of Distilled Water Extract Samples that Exceed Specified Standard, by Parameter Measured and Waste Type (continued)

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples[a] | Standards Specifying Limits for These Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations | | National Secondary Drinking Water Regulations | | Ambient Water Quality Criteria for Human Health | | Ambient Water Quality Criteria for Freshwater Aquatic Life | |
| | | | | (1X) | (100X) | (1X) | (100X) | (1X) | (100X) | (1X) | (100X) |
| Fe (Iron) | | | | | | | | | | | |
| Mine Waste | 110 | NA | NA | NA | NA | 7 | 0 | NA | NA | NA | NA |
| Tailings | 71 | NA | NA | NA | NA | 6 | 1 | NA | NA | NA | NA |
| Leachate | 7 | NA | NA | NA | NA | 4 | 1 | NA | NA | NA | NA |
| Hg (Mercury) | | | | | | | | | | | |
| Mine Waste | 112 | 0 | 0 | 7 | 0 | NA | NA | 109 | 2 | 112 | 8 |
| Tailings | 71 | 0 | 0 | 9 | 0 | NA | NA | 69 | 5 | 71 | 9 |
| Leachate | 7 | 0 | 0 | 0 | 0 | NA | NA | 7 | 0 | 7 | 0 |
| Mn (Manganese) | | | | | | | | | | | |
| Mine Waste | 110 | NA | NA | NA | NA | 55 | 2 | NA | NA | NA | NA |
| Tailings | 71 | NA | NA | NA | NA | 41 | 3 | NA | NA | NA | NA |
| Leachate | 7 | NA | NA | NA | NA | 6 | 3 | NA | NA | NA | NA |
| Ni (Nickel) | | | | | | | | | | | |
| Mine Waste | 110 | 0 | NA | NA | NA | NA | NA | 78 | 0 | 4 | 0 |
| Tailings | 71 | 0 | NA | NA | NA | NA | NA | 52 | 0 | 5 | 0 |
| Leachate | 7 | 0 | NA | NA | NA | NA | NA | 6 | 0 | 5 | 0 |
| Pb (Lead) | | | | | | | | | | | |
| Mine Waste | 110 | 0 | 0 | 110 | 0 | NA | NA | 110 | 0 | 110 | 0 |
| Tailings | 71 | 0 | 0 | 71 | 0 | NA | NA | 71 | 0 | 71 | 0 |
| Leachate | 7 | 0 | 0 | 7 | 0 | NA | NA | 7 | 0 | 7 | 0 |
| Se (Selenium) | | | | | | | | | | | |
| Mine Waste | 112 | 0 | 0 | 29 | 0 | NA | NA | 29 | 0 | 29 | 0 |
| Tailings | 71 | 0 | 0 | 25 | 0 | NA | NA | 25 | 0 | 25 | 0 |
| Leachate | 7 | 0 | 0 | 3 | 0 | NA | NA | 3 | 0 | 3 | 0 |
| Tl (Thallium) | | | | | | | | | | | |
| Mine Waste | 110 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Tailings | 71 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Leachate | 7 | 0 | NA | NA | NA | NA | NA | NA | NA | NA | NA |

Table 4. Number of Distilled Water Extract Samples that Exceed Specified Standard, by Parameter Measured and Waste Type (continued)

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples[a] | Standards Specifying Limits for These Parameters: Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations (1X) | National Primary Drinking Water Regulations (100X) | National Secondary Drinking Water Regulations (1X) | National Secondary Drinking Water Regulations (100X) | Ambient Water Quality Criteria for Human Health (1X) | Ambient Water Quality Criteria for Human Health (100X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (1X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (100X) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Zn (Zinc) | | | | | | | | | | | |
| Mine Waste | 110 | NA | NA | NA | NA | 1 | 0 | 1 | 0 | NA | NA |
| Tailings | 71 | NA | NA | NA | NA | 1 | 0 | 1 | 0 | NA | NA |
| Leachate | 7 | NA | NA | NA | NA | 1 | 0 | 1 | 0 | NA | NA |
| $NO_3$(Nitrate) | | | | | | | | | | | |
| Mine Waste | 104 | NA | NA | 0 | 0 | NA | NA | NA | NA | NA | NA |
| Tailings | 68 | NA | NA | 0 | 0 | NA | NA | NA | NA | NA | NA |
| Leachate | 4 | NA | NA | 0 | 0 | NA | NA | NA | NA | NA | NA |
| F (Fluoride) | | | | | | | | | | | |
| Mine Waste | 104 | NA | NA | 0 | 0 | 4 | 0 | NA | NA | NA | NA |
| Tailings | 68 | NA | NA | 2 | 0 | 6 | 0 | NA | NA | NA | NA |
| Leachate | 4 | NA | NA | 0 | 0 | 1 | 0 | NA | NA | NA | NA |
| $SO_4$(Sulfate) | | | | | | | | | | | |
| Mine Waste | 104 | NA | NA | NA | NA | 4 | 0 | NA | NA | NA | NA |
| Tailings | 68 | NA | NA | NA | NA | 15 | 0 | NA | NA | NA | NA |
| Leachate | 4 | NA | NA | NA | NA | 1 | 0 | NA | NA | NA | NA |

Source: Meridian Research, Inc.

NA = Not Applicable.

[a] Excludes PEDCo liquid samples.

ambient water quality criteria standard for aquatic life. In these cases, the limits specified by the standards are one or two orders of magnitude lower than the lowest detectable level reported in the sources of the mining waste data. Table 4 shows a similar finding for water extracts of samples analyzed for lead, where 100 percent of all samples exceed the primary drinking water standard and both water quality criteria for human health and aquatic life. This result arose because the lowest level of lead reported for water extracts of samples is 0.06 mg/l, which is higher than the limits specified by these standards for lead (0.05 mg/l) and one or two orders of magnitude higher than the detection limit reported for any other metal. Sixty-three percent of the water extracts analyzed for lead content exceed the reported detection limit of 0.06 mg/l. This result is comparable to the 74 percent of acid extracts of lead samples that exceed the limits for lead specified by the primary drinking water standards and the water quality criteria for human health, suggesting that acid and water extraction are equally efficient in leaching out small quantities of lead.

However, when the lead content of water and acid extracts are compared to 100 times the limits specified by the primary drinking water standard and water quality criteria (i.e., 5 mg/l), a different pattern emerges. Five percent of the acid extract samples have lead content exceeding 5 mg/l, while none of the water extract samples had lead content exceeding this level. This suggests that acid extraction is more efficient than water extraction for leaching out larger quantities of lead.

Little difference in the percentage of samples exceeding the various standards was observed between acid and water extracts of samples analyzed for silver, beryllium, mercury, or selenium. For each of the other metals and anions analyzed, a greater percentage of acid extracts exceed the limits

specified by the various standards (and 100 times these limits) than do water extracts. The parameters for which this observation was most pronounced include arsenic, barium, cadmium, chromium, copper, iron, zinc, fluoride, and sulfate. To a lesser extent, acid extraction was more effective than water extraction for leaching nickel and selenium, particularly at levels exceeding 100 times the limits specified for nickel and selenium. In general, the results of the comparative analysis show that, with few exceptions, acetic acid extraction is a more aggressive leaching technique for metals and anions than is water extraction.

The number of liquid samples analyzed for ammonia, pH, total dissolved solids (TDS), turbidity (TURB), or cyanide that exceed the various standards and criteria are presented in Table 5. Most of the samples analyzed for ammonia, TDS, TURB, or cyanide exceed the various standards and criteria. Approximately half of the samples analyzed for pH fall outside the limits specified by the secondary drinking water standard, but few samples would be characterized as being hazardous by the criteria established under RCRA Subtitle C or the 1984 RCRA Amendments. All samples analyzed for free cyanide exceed the limit specified by the ambient water quality criteria for aquatic life, while half the samples exceed the water quality criteria for human health.

## 3.0 ANALYSIS OF RELATIONSHIPS BETWEEN METAL CONTENT OF RAW SAMPLES, ACID EXTRACTS, OR WATER EXTRACTS

Data on solid mining waste samples reported by PEDCo included data on the metal content of raw samples, acetic acid extracts, and distilled water extracts. In this section of the report, Meridian examines whether or not any relationships exist between metal content of raw samples and that of the extracts.

Table 5. Number of Liquid Samples that Exceed Specified Standard, by Parameter Measured and Waste Type

| Mining Waste Parameters Measured and Waste Type | Total Number of Samples | Standards Specifying Limits for These Parameters: Limits for Liquids in Landfills Set by 1984 RCRA Amendments | RCRA Subtitle C Characteristics of Hazardous Waste | National Primary Drinking Water Regulations (1X) | National Primary Drinking Water Regulations (100X) | National Secondary Drinking Water Regulations (1X) | National Secondary Drinking Water Regulations (100X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (1X) | Ambient Water Quality Criteria for Freshwater Aquatic Life (100X) | Ambient Water Quality Criteria for Human Health (1X) | Ambient Water Quality Criteria for Human Health (100X) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $NH_3$ (Ammonia) | | | | | | | | | | | |
| Mine Waste | 40 | NA | NA | NA | NA | NA | NA | 40[a] (25)[b] | 36[a] (3)[b] | NA | NA |
| Tailings | 42 | NA | NA | NA | NA | NA | NA | 42[a] (31)[b] | 36[a] (12)[b] | NA | NA |
| Leachate | 5 | NA | NA | NA | NA | NA | NA | 5[a] (4)[b] | 4[a] (3)[b] | NA | NA |
| pH Mine Waste | 63 | 0 | 0 | NA | NA | 21 | NA | NA | NA | NA | NA |
| Tailings | 83 | 1 | 2 | NA | NA | 37 | NA | NA | NA | NA | NA |
| Leachate | 13 | 3 | 3 | NA | NA | 10 | NA | NA | NA | NA | NA |
| TDS Mine Waste | 65 | NA | NA | NA | NA | 49 | 0 | NA | NA | NA | NA |
| Tailings | 73 | NA | NA | NA | NA | 50 | 0 | NA | NA | NA | NA |
| Leachate | 13 | NA | NA | NA | NA | 12 | 4 | NA | NA | NA | NA |
| TURB (Turbidity) | | | | | | | | | | | |
| Mine Waste | 40 | NA | NA | 40 | 32 | NA | NA | NA | NA | NA | NA |
| Tailings | 41 | NA | NA | 41 | 31 | NA | NA | NA | NA | NA | NA |
| Leachate | 5 | NA | NA | 5 | 3 | NA | NA | NA | NA | NA | NA |
| CN (Cyanide) | | | | | | | | | | | |
| All Samples | 27 | 0 | NA | NA | NA | NA | NA | 27 | 12 | 12 | 4 |

Source: Meridian Research, Inc.

NA = Not Applicable.

[a] Number of samples that exceed ammonia standard in water with a pH = 6.5.

[b] Number of samples that exceed ammonia standard in water with a pH = 8.0.

## 3.1 METHODS USED

To conduct this analysis, Meridian collapsed the mining waste data base to include only those solid samples that were analyzed for metal content in raw samples, acid extracts, and distilled water extracts. Samples analyzed for six of the seven EP toxic metals were included in the analysis (there were no silver samples that were analyzed concurrently for silver content in raw samples, acid extracts, and water extracts). Least-squares regression analyses were used to determine the degree of correlation between metal content in raw samples or the extracts. All regressions were performed using the regression analysis routine contained in Lotus 1-2-3 (Version 2). For each metal, the following relationships were examined:

$$M_A = a_0 + a_1 M_T$$

$$M_A = a_0 + a_1 M_T^{(1/2)}$$

$$M_A = a_0 + a_1 M_T^{(1/3)}$$

$$M_A = a_0 + a_1 M_T + a_2 M_T^{(1/2)} + a_3 M_T^{(1/3)}$$

$$M_A = a_0 + a_1 \ln M_T$$

$$\ln M_A = a_0 + a_1 \ln M_T$$

$$M_W = a_0 + a_1 M_T$$

$$M_W = a_0 + a_1 M_T^{(1/2)}$$

$$M_W = a_0 + a_1 M_T^{(1/3)}$$

$$M_W = a_0 + a_1 M_T + a_2 M_T^{(1/2)} + a_3 M_T^{(1/3)}$$

$$M_W = a_0 + a_1 \ln M_T$$

$$\ln M_W = a_0 + a_1 \ln M_T$$

$$M_A = a_0 + a_1 M_W$$

$$\ln M_A = a_0 + a_1 \ln M_W$$

where

$M_T$ = total metal content in raw sample

$M_A$ = metal content in acid extract

$M_W$ = metal content in water extract

$a_0$ = constant (y-intercept)

$a_1$, $a_2$, $a_3$ = x-coefficient(s).

The output generated by the regression program provided the values of the constant ($a_0$) and x-coefficients ($a_1$, $a_2$, $a_3$), the standard error of $a_0$, the standard error of the x-coefficients, the number of samples, the degrees of freedom, and the correlation coefficient ($R^2$). Regressions that resulted in an $R^2$ value greater than 0.3 were considered to be indicative of a true relationship between the terms examined ($M_T$, $M_A$, or $M_W$). This is generally the case for cross-sectional data such as that represented by the mining waste data set. All regressions reported in this section allowed for the calculation of the constant value $a_0$; forcing the y-intercept through zero resulted, in most cases, in a small change in the $R^2$ value or, occasionally, in an $R^2$ value of 0. The outputs from all regressions performed appear in Appendix A. Appendix B contains graphic representations of regressions with the highest degree of correlation between the regression terms. The results of the more significant regression analyses are summarized below, by metal.

## 3.2 REGRESSION RESULTS

### 3.2.1 Barium

The results of the regression analysis indicate that there is a correlation between barium content in raw samples and barium content in acid extract; the correlation coefficient ($R^2$) for this relationship was 0.38. A

correlation between barium content in raw samples and in water extract was less evident ($R^2$ = 0.19). An excellent degree of correlation ($R^2$ = 0.70) was observed between barium content in acid extract versus water extract. The graph depicting the latter reltaionship (Figure 2, Appendix B) reveals that, in general, acid extract samples will contain approximately six times more barium than will water extract samples. This relationship was also reflected by the analysis presented in Section 2.2, which shows that 8 percent of acid extract samples exceed the primary drinking water standard for barium, compared to only 2 percent of water extract samples.

### 3.2.2 Chromium

No correlation was observed between chromium content in raw samples and either acid extract ($R^2$ = 0.004) or water extract ($R^2$ = 0.003). A high degree of correlation ($R^2$ = 0.75) was observed between chromium content in acid extract versus water extract, with the x- and y-coefficients indicating an approximate one-to-one reltaionship. This finding appears to contradict the result of the comparative analysis, which shows that 37 percent of acid extract samples exceed the limits for chromium specified by the primary drinking water standards and water quality criteria for human health, compared to only 4 percent of water extracts (see Tables 3 and 4). Examination of Figure 3 in Appendix B suggests an explanation for this discrepancy. At chromium concentrations below 0.05 mg/l (the limits of the above-mentioned standards), the relationship between acid extract and water extract samples approaches a one-to-one relationship; this relationship does not hold for samples above 0.05 mg/l, where there are comparatively few water extract samples. Thus, in the case of chromium samples, it appears that the regression is being driven by the samples that contain chromium levels below the limits specified by the drinking water and water quality criteria.

### 3.2.3 Lead

Regression analyses conducted on samples analyzed for lead indicate a correlation between the natural logarithm of lead content in raw samples versus the natural logarithm of lead content in acid extract ($R^2 = 0.56$). No other correlations between the results for the various types of lead samples were evident. These results suggest that the lead content in acid extracts reflects (in a non-linear fashion) the lead content in the raw samples. On the other hand, the lead content in water extracts does not reflect the lead content present in the raw samples. Despite the different results obtained in the regressions of acid and water extract samples, there was little difference in the percentage of acid and water extract samples that exceeds the 0.05 mg/l specified by the primary drinking water standards and water quality criteria for human health. (See discussion in Section 2.2)

### 3.2.4 Analyses of Samples of Other Metals

Regressions performed on samples analyzed for silver, cadmium, and mercury failed to identify any correlation between metal content in raw samples, acid extracts, or water extracts.

### 3.2.5 Conclusions

For four of the six metals examined, there was no clear relationship between the amount of metal in raw mining waste samples and the metal content of acid extracts of these samples. The results indicate that there is a linear relationship between barium content in raw samples versus acid extracts, and a non-linear relationship between lead content in raw samples versus acid extracts. There does not appear to be any simple relationship between metal content in raw samples and metal content in water extracts.

Metal content of acid extracts correlated with metal content of water extracts for only two of the six metals examined (barium and chromium).

These results suggest that, in general, the metal content of acetic acid or distilled water extracts will not reflect, according to any simple formula, the presence of the metal in the raw waste sample. This is perhaps not surprising, given that the mining waste data were generated by analyzing several types of mining waste at 99 mine and mill operations. Thus, these data represent a mineralogically diverse set of samples with different chemical and physical properties that are likely to affect the susceptibility of various metals to leaching.

# APPENDIX A

# REGRESSION ANALYSIS FOR ARSENIC SAMPLES

$AS_A = a_0 + a_1 AS_T$

| Regression Output: | |
|---|---|
| Constant | 0.01653130 |
| Std Err of Y Est | 0.04084793 |
| R Squared | 0.02366382 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00283963 |
| Std Err of Coef. | 0.00001752 |

$AS_A = a_0 + a_1 \ln(AS_T)$

| Regression Output: | |
|---|---|
| Constant | 0.01379011 |
| Std Err of Y Est | 0.04116361 |
| R Squared | 0.00851522 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00207345 |
| Std Err of Coef. | 0.00154027 |

$AS_A = a_0 + a_1 AS_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.01217448 |
| Std Err of Y Est | 0.04079159 |
| R Squared | 0.02635545 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00142394 |
| Std Err of Coef. | 0.00059582 |

$\ln(AS_A) = a_0 + a_1 \ln(AS_T)$

| Regression Output: | |
|---|---|
| Constant | -5.3578673 |
| Std Err of Y Est | 1.66515854 |
| R Squared | 0.03703404 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.07617587 |
| Std Err of Coef. | 0.06230758 |

$AS_A = a_0 + a_1 AS_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.00890091 |
| Std Err of Y Est | 0.04092379 |
| R Squared | 0.02099182 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00391249 |
| Std Err of Coef. | 0.00183941 |

$AS_W = a_0 + a_1 AS_T$

| Regression Output: | |
|---|---|
| Constant | 0.00974169 |
| Std Err of Y Est | 0.06552777 |
| R Squared | 0.16254482 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00017993 |
| Std Err of Coef. | 0.00002811 |

$AS_A = a_0 + a_1 AS_T + a_2 AS_T^{(1/2)} + a_3 AS_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.03019641 |
| Std Err of Y Est | 0.04080884 |
| R Squared | 0.03476837 |
| No. of Observations | 213 |
| Degrees of Freedom | 209 |

| | | | |
|---|---|---|---|
| X Coefficient(s) | -0.0000991 | 0.01233781 | -0.0250464 |
| Std Err of Coef. | 0.00009256 | 0.00866667 | 0.01984753 |

$AS_W = a_0 + a_1 AS_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | -0.0098147 |
| Std Err of Y Est | 0.06491819 |
| R Squared | 0.17805346 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00641074 |
| Std Err of Coef. | 0.00094822 |

## REGRESSION ANALYSIS FOR ARSENIC SAMPLES (CONTINUED)

$AS_W = a_0 + a_1 AS_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -0.0248558 |
| Std Err of Y Est | 0.06637241 |
| R Squared | 0.14081664 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.01755214 |
| Std Err of Coef. | 0.00298472 |

$\ln(AS_W) = a_0 + a_1 \ln(AS_T)$

| Regression Output: | |
|---|---|
| Constant | -5.6761669 |
| Std Err of Y Est | 1.28728745 |
| R Squared | 0.09243847 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.28942359 |
| Std Err of Coef. | 0.04517477 |

$AS_W = a_0 + a_1 AS_T + a_2 AS_T^{(1/2)} + a_3 AS_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.07120485 |
| Std Err of Y Est | 0.06294024 |
| R Squared | 0.23470055 |
| No. of Observations | 213 |
| Degrees of Freedom | 209 |

| | | | |
|---|---|---|---|
| X Coefficient(s) | -0.0004345 | 0.05484621 | -0.1116844 |
| Std Err of Coef. | 0.00014277 | 0.01336677 | 0.02937737 |

$AS_A = a_0 + a_1 AS_W$

| Regression Output: | |
|---|---|
| Constant | 0.01548863 |
| Std Err of Y Est | 0.03982978 |
| R Squared | 0.07173206 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.15462597 |
| Std Err of Coef. | 0.03829316 |

$AS_W = a_0 + a_1 \ln(AS_T)$

| Regression Output: | |
|---|---|
| Constant | -0.0007652 |
| Std Err of Y Est | 0.06988571 |
| R Squared | 0.04745059 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.00847797 |
| Std Err of Coef. | 0.00261581 |

$\ln(AS_A) = a_0 + a_1 \ln(AS_W)$

| Regression Output: | |
|---|---|
| Constant | -3.4036592 |
| Std Err of Y Est | 1.61363303 |
| R Squared | 0.06753459 |
| No. of Observations | 213 |
| Degrees of Freedom | 211 |

| | |
|---|---|
| X Coefficient(s) | 0.34267222 |
| Std Err of Coef. | 0.08765786 |

# REGRESSION ANALYSIS FOR BARIUM SAMPLES

$BA_A = a_0 + a_1 BA_T$

| Regression Output: | |
|---|---|
| Constant | -2.07698651 |
| Std Err of Y Est | 3.623232526 |
| R Squared | 0.382311721 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.008854359 |
| Std Err of Coef. | 0.000782254 |

$BA_A = a_0 + a_1 \ln(BA_T)$

| Regression Output: | |
|---|---|
| Constant | -3.23217589 |
| Std Err of Y Est | 4.497614267 |
| R Squared | 0.048209514 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.775566234 |
| Std Err of Coef. | 0.239517924 |

$BA_A = a_0 + a_1 BA_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | -2.82482553 |
| Std Err of Y Est | 4.214577628 |
| R Squared | 0.164233302 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.226117823 |
| Std Err of Coef. | 0.035453698 |

$\ln(BA_A) = a_0 + a_1 \ln(BA_T)$

| Regression Output: | |
|---|---|
| Constant | -3.01450736 |
| Std Err of Y Est | 1.635606058 |
| R Squared | 0.025734462 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.203675401 |
| Std Err of Coef. | 0.087103283 |

$BA_A = a_0 + a_1 BA_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -3.46468575 |
| Std Err of Y Est | 4.348476546 |
| R Squared | 0.113555040 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.693470250 |
| Std Err of Coef. | 0.134668288 |

$BA_W = a_0 + a_1 BA_T$

| Regression Output: | |
|---|---|
| Constant | -0.03303946 |
| Std Err of Y Est | 0.407416451 |
| R Squared | 0.195148515 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.000623160 |
| Std Err of Coef. | 0.000087961 |

$BA_A = a_0 + a_1 BA_T + a_2 BA_T^{(1/2)} + a_3 BA_T^{(1/3)}$

| Regression Output: | | | |
|---|---|---|---|
| Constant | -10.4211785 | | |
| Std Err of Y Est | 2.568292590 | | |
| R Squared | 0.692638504 | | |
| No. of Observations | 209 | | |
| Degrees of Freedom | 205 | | |
| X Coefficient(s) | 0.054002811 | -4.91860511 | 11.77151754 |
| Std Err of Coef. | 0.004223263 | 0.615572477 | 1.745167831 |

$BA_W = a_0 + a_1 BA_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | -0.11669029 |
| Std Err of Y Est | 0.429543442 |
| R Squared | 0.105350730 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.017839887 |
| Std Err of Coef. | 0.003613387 |

## REGRESSION ANALYSIS FOR BARIUM SAMPLES (CONTINUED)

$BA_W = a_0 + a_1 BA_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -0.17900600 |
| Std Err of Y Est | 0.436049317 |
| R Squared | 0.078044737 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.056632482 |
| Std Err of Coef. | 0.013528932 |

$\ln(BA_W) = a_0 + a_1 \ln(BA_T)$

| Regression Output: | |
|---|---|
| Constant | -2.94943238 |
| Std Err of Y Est | 0.972355539 |
| R Squared | 0.026206353 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.122218286 |
| Std Err of Coef. | 0.051782248 |

$BA_W = a_0 + a_1 BA_T + a_2 BA_T^{(1/2)} + a_3 BA_T^{(1/3)}$

| Regression Output: | | | |
|---|---|---|---|
| Constant | 0.075264986 | | |
| Std Err of Y Est | 0.392503314 | | |
| R Squared | 0.260209416 | | |
| No. of Observations | 209 | | |
| Degrees of Freedom | 205 | | |
| X Coefficient(s) | 0.001954061 | -0.09971582 | 0.172074028 |
| Std Err of Coef. | 0.000645426 | 0.094075822 | 0.266707991 |

$BA_A = a_0 + a_1 BA_W$

| Regression Output: | |
|---|---|
| Constant | -0.63576854 |
| Std Err of Y Est | 2.518544265 |
| R Squared | 0.701546879 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.502745652 |
| Std Err of Coef. | 0.385463915 |

$BA_W = a_0 + a_1 \ln(BA_T)$

| Regression Output: | |
|---|---|
| Constant | -0.17703687 |
| Std Err of Y Est | 0.445734182 |
| R Squared | 0.036635792 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.066600036 |
| Std Err of Coef. | 0.023737323 |

$\ln(BA_A) = a_0 + a_1 \ln(BA_W)$

| Regression Output: | |
|---|---|
| Constant | 0.228434133 |
| Std Err of Y Est | 1.371852462 |
| R Squared | 0.314614781 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.943274246 |
| Std Err of Coef. | 0.096767742 |

# REGRESSION ANALYSIS FOR CADMIUM SAMPLES

$CD_A = a_0 + a_1 CD_T$

| Regression Output: | |
|---|---|
| Constant | 0.018720630 |
| Std Err of Y Est | 0.049130775 |
| R Squared | 0.052254679 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.000102974 |
| Std Err of Coef. | 0.000030629 |

$CD_A = a_0 + a_1 CD_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.007232276 |
| Std Err of Y Est | 0.048263165 |
| R Squared | 0.085431962 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.003318175 |
| Std Err of Coef. | 0.000758263 |

$CD_A = a_0 + a_1 CD_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -0.00623910 |
| Std Err of Y Est | 0.048084715 |
| R Squared | 0.092182582 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.010925308 |
| Std Err of Coef. | 0.002394592 |

$CD_A = a_0 + a_1 CD_T + a_2 CD_T^{(1/2)} + a_3 CD_T^{(1/3)}$

| Regression Output: | | | |
|---|---|---|---|
| Constant | -0.13869807 | | |
| Std Err of Y Est | 0.047958074 | | |
| R Squared | 0.105768272 | | |
| No. of Observations | 207 | | |
| Degrees of Freedom | 203 | | |
| X Coefficient(s) | 0.000288331 | -0.04760450 | 0.148457244 |
| Std Err of Coef. | 0.000469353 | 0.056150555 | 0.143961266 |

$CD_A = a_0 + a_1 \ln(CD_T)$

| Regression Output: | |
|---|---|
| Constant | -0.01810196 |
| Std Err of Y Est | 0.047869141 |
| R Squared | 0.100304191 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.015132817 |
| Std Err of Coef. | 0.003165418 |

$\ln(CD_A) = a_0 + a_1 \ln(CD_T)$

| Regression Output: | |
|---|---|
| Constant | -4.93393808 |
| Std Err of Y Est | 0.761975261 |
| R Squared | 0.101443765 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.242400427 |
| Std Err of Coef. | 0.050386756 |

$CD_W = a_0 + a_1 CD_T$

| Regression Output: | |
|---|---|
| Constant | 0.012335524 |
| Std Err of Y Est | 0.015199044 |
| R Squared | 0.004793978 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.000009416 |
| Std Err of Coef. | 0.000009475 |

$CD_W = a_0 + a_1 CD_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.011014330 |
| Std Err of Y Est | 0.015151290 |
| R Squared | 0.011037983 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |
| X Coefficient(s) | 0.000360867 |
| Std Err of Coef. | 0.000238042 |

## REGRESSION ANALYSIS FOR CADMIUM SAMPLES (CONTINUED)

$CD_W = a_0 + a_1 CD_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.009461822 |
| Std Err of Y Est | 0.015139331 |
| R Squared | 0.012598498 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |

| | |
|---|---|
| X Coefficient(s) | 0.001219328 |
| Std Err of Coef. | 0.000753930 |

$\ln(CD_W) = a_0 + a_1 \ln(CD_T)$

| Regression Output: | |
|---|---|
| Constant | -4.65601148 |
| Std Err of Y Est | 0.556686100 |
| R Squared | 0.002420333 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |

| | |
|---|---|
| X Coefficient(s) | 0.025961313 |
| Std Err of Coef. | 0.036811702 |

$CD_W = a_0 + a_1 CD_T + a_2 CD_T^{(1/2)} + a_3 CD_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.001625413 |
| Std Err of Y Est | 0.015172587 |
| R Squared | 0.017931275 |
| No. of Observations | 207 |
| Degrees of Freedom | 203 |

| | | | |
|---|---|---|---|
| X Coefficient(s) | -0.00000837 | -0.00172581 | 0.007268690 |
| Std Err of Coef. | 0.000148490 | 0.017764457 | 0.045545299 |

$CD_A = a_0 + a_1 CD_W$

| Regression Output: | |
|---|---|
| Constant | 0.015129746 |
| Std Err of Y Est | 0.049561018 |
| R Squared | 0.035583081 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |

| | |
|---|---|
| X Coefficient(s) | 0.624840663 |
| Std Err of Coef. | 0.227197472 |

$CD_W = a_0 + a_1 \ln(CD_T)$

| Regression Output: | |
|---|---|
| Constant | 0.007974663 |
| Std Err of Y Est | 0.015123218 |
| R Squared | 0.014699067 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |

| | |
|---|---|
| X Coefficient(s) | 0.001748868 |
| Std Err of Coef. | 0.001000045 |

$\ln(CD_A) = a_0 + a_1 \ln(CD_W)$

| Regression Output: | |
|---|---|
| Constant | -2.37711818 |
| Std Err of Y Est | 0.770053529 |
| R Squared | 0.082290241 |
| No. of Observations | 207 |
| Degrees of Freedom | 205 |

| | |
|---|---|
| X Coefficient(s) | 0.413719341 |
| Std Err of Coef. | 0.096495575 |

## REGRESSION ANALYSIS FOR CHROMIUM SAMPLES

$CR_A = a_0 + a_1 CR_T$

| Regression Output: | |
|---|---|
| Constant | 0.038965683 |
| Std Err of Y Est | 0.095086466 |
| R Squared | 0.004433413 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.000024968 |
| Std Err of Coef. | 0.000026068 |

$CR_A = a_0 + a_1 \ln(CR_T)$

| Regression Output: | |
|---|---|
| Constant | 0.001523330 |
| Std Err of Y Est | 0.094860718 |
| R Squared | 0.009155021 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.008553543 |
| Std Err of Coef. | 0.006199913 |

$CR_A = a_0 + a_1 CR_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.021449779 |
| Std Err of Y Est | 0.094808821 |
| R Squared | 0.010238868 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.001559412 |
| Std Err of Coef. | 0.001068234 |

$\ln(CR_A) = a_0 + a_1 \ln(CR_T)$

| Regression Output: | |
|---|---|
| Constant | -3.64236138 |
| Std Err of Y Est | 1.628871347 |
| R Squared | 0.030482600 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | -0.27093669 |
| Std Err of Coef. | 0.106459887 |

$CR_A = a_0 + a_1 CR_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.011351614 |
| Std Err of Y Est | 0.094768407 |
| R Squared | 0.011082496 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.005927186 |
| Std Err of Coef. | 0.003981002 |

$CR_W = a_0 + a_1 CR_T$

| Regression Output: | |
|---|---|
| Constant | 0.017508632 |
| Std Err of Y Est | 0.075592165 |
| R Squared | 0.003492004 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.000017687 |
| Std Err of Coef. | 0.000020724 |

$CR_A = a_0 + a_1 CR_T + a_2 CR_T^{(1/2)} + a_3 CR_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.201087593 |
| Std Err of Y Est | 0.093867160 |
| R Squared | 0.039221667 |
| No. of Observations | 208 |
| Degrees of Freedom | 204 |

| | | | |
|---|---|---|---|
| X Coefficient(s) | -0.00060376 | 0.074155197 | -0.18208754 |
| Std Err of Coef. | 0.000248619 | 0.032109662 | 0.034290676 |

$CR_W = a_0 + a_1 CR_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.009107285 |
| Std Err of Y Est | 0.075282694 |
| R Squared | 0.011634613 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.001320881 |
| Std Err of Coef. | 0.000848228 |

## REGRESSION ANALYSIS FOR CHROMIUM SAMPLES (CONTINUED)

$CR_W = a_0 + a_1 CR_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -0.00034303 |
| Std Err of Y Est | 0.075198907 |
| R Squared | 0.013833427 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.005261959 |
| Std Err of Coef. | 0.003095452 |

$\ln(CR_W) = a_0 + a_1 \ln(CR_T)$

| Regression Output: | |
|---|---|
| Constant | -4.10530988 |
| Std Err of Y Est | 1.467660972 |
| R Squared | 0.033773641 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | -0.25739972 |
| Std Err of Coef. | 0.095923488 |

$CR_W = a_0 + a_1 CR_T + a_2 CR_T^{(1/2)} + a_3 CR_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.146381198 |
| Std Err of Y Est | 0.074189817 |
| R Squared | 0.049441695 |
| No. of Observations | 208 |
| Degrees of Freedom | 204 |

| | | | |
|---|---|---|---|
| X Coefficient(s) | -0.00251905 | 0.060910954 | -0.14611740 |
| Std Err of Coef. | 0.000196501 | 0.025378523 | 0.066620848 |

$CR_A = a_0 + a_1 CR_W$

| Regression Output: | |
|---|---|
| Constant | 0.012495216 |
| Std Err of Y Est | 0.048025304 |
| R Squared | 0.746035420 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 1.086993337 |
| Std Err of Coef. | 0.044187570 |

$CR_W = a_0 + a_1 \ln(CR_T)$

| Regression Output: | |
|---|---|
| Constant | -0.01173451 |
| Std Err of Y Est | 0.075204586 |
| R Squared | 0.013684490 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.008309665 |
| Std Err of Coef. | 0.004915226 |

$\ln(CR_A) = a_0 + a_1 \ln(CR_W)$

| Regression Output: | |
|---|---|
| Constant | -1.75516416 |
| Std Err of Y Est | 1.416954143 |
| R Squared | 0.266445596 |
| No. of Observations | 208 |
| Degrees of Freedom | 206 |

| | |
|---|---|
| X Coefficient(s) | 0.571909023 |
| Std Err of Coef. | 0.066115795 |

## REGRESSION ANALYSIS FOR MERCURY SAMPLES

$HG_A = a_0 + a_1 HG_T$

| Regression Output: | |
|---|---|
| Constant | 0.003231429 |
| Std Err of Y Est | 0.008337632 |
| R Squared | 0.001445948 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | 0.000506541 |
|---|---|
| Std Err of Coef. | 0.000922981 |

$HG_A = a_0 + a_1 \ln(HG_T)$

| Regression Output: | |
|---|---|
| Constant | 0.000970364 |
| Std Err of Y Est | 0.008228526 |
| R Squared | 0.027489015 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | -0.00095087 |
|---|---|
| Std Err of Coef. | 0.000392743 |

$HG_A = a_0 + a_1 HG_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.004007058 |
| Std Err of Y Est | 0.008323574 |
| R Squared | 0.004810415 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | -0.00173116 |
|---|---|
| Std Err of Coef. | 0.001726509 |

$\ln(HG_A) = a_0 + a_1 \ln(HG_T)$

| Regression Output: | |
|---|---|
| Constant | -7.56980480 |
| Std Err of Y Est | 1.461227190 |
| R Squared | 0.016590022 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | -0.13064506 |
|---|---|
| Std Err of Coef. | 0.06974373 |

$HG_A = a_0 + a_1 HG_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.005154627 |
| Std Err of Y Est | 0.008287221 |
| R Squared | 0.013484397 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | -0.00367958 |
|---|---|
| Std Err of Coef. | 0.002182246 |

$HG_W = a_0 + a_1 HG_T$

| Regression Output: | |
|---|---|
| Constant | 0.002919363 |
| Std Err of Y Est | 0.012170813 |
| R Squared | 0.005128028 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | 0.001395060 |
|---|---|
| Std Err of Coef. | 0.001347317 |

$HG_A = a_0 + a_1 HG_T + a_2 HG_T^{(1/2)} + a_3 HG_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.013373389 |
| Std Err of Y Est | 0.008035868 |
| R Squared | 0.081338405 |
| No. of Observations | 210 |
| Degrees of Freedom | 206 |

| X Coefficient(s) | 0.001073552 | 0.031536193 | -0.04527142 |
|---|---|---|---|
| Std Err of Coef. | 0.007023366 | 0.040608258 | 0.037262211 |

$HG_W = a_0 + a_1 HG_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.001780362 |
| Std Err of Y Est | 0.012129562 |
| R Squared | 0.011860549 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| X Coefficient(s) | 0.003975385 |
|---|---|
| Std Err of Coef. | 0.002515963 |

## REGRESSION ANALYSIS FOR MERCURY SAMPLES (CONTINUED)

$HG_W = a_0 + a_1 HG_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | 0.000537054 |
| Std Err of Y Est | 0.012112780 |
| R Squared | 0.014592981 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| | |
|---|---|
| X Coefficient(s) | 0.005598020 |
| Std Err of Coef. | 0.003189617 |

$\ln(HG_W) = a_0 + a_1 \ln(HG_T)$

| Regression Output: | |
|---|---|
| Constant | -6.92387684 |
| Std Err of Y Est | 1.267533133 |
| R Squared | 0.034977682 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| | |
|---|---|
| X Coefficient(s) | 0.166113621 |
| Std Err of Coef. | 0.060498798 |

$HG_W = a_0 + a_1 HG_T + a_2 HG_T^{(1/2)} + a_3 HG_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -0.00210889 |
| Std Err of Y Est | 0.012150414 |
| R Squared | 0.017994347 |
| No. of Observations | 210 |
| Degrees of Freedom | 206 |

| | | | |
|---|---|---|---|
| X Coefficient(s) | -0.00042582 | -0.00990408 | 0.018838501 |
| Std Err of Coef. | 0.010619488 | 0.061400604 | 0.056341306 |

$HG_A = a_0 + a_1 HG_W$

| Regression Output: | |
|---|---|
| Constant | 0.003520892 |
| Std Err of Y Est | 0.008321645 |
| R Squared | 0.005271539 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| | |
|---|---|
| X Coefficient(s) | -0.04964661 |
| Std Err of Coef. | 0.047286975 |

$HG_W = a_0 + a_1 \ln(HG_T)$

| Regression Output: | |
|---|---|
| Constant | 0.003839499 |
| Std Err of Y Est | 0.012197686 |
| R Squared | 0.000729968 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| | |
|---|---|
| X Coefficient(s) | 0.000226938 |
| Std Err of Coef. | 0.000582190 |

$\ln(HG_A) = a_0 + a_1 \ln(HG_W)$

| Regression Output: | |
|---|---|
| Constant | -8.73931330 |
| Std Err of Y Est | 1.449799213 |
| R Squared | 0.031913328 |
| No. of Observations | 210 |
| Degrees of Freedom | 208 |

| | |
|---|---|
| X Coefficient(s) | -0.20400736 |
| Std Err of Coef. | 0.077908573 |

# REGRESSION ANALYSIS FOR LEAD SAMPLES

$PB_A = a_0 + a_1 PB_T$

| Regression Output: | |
|---|---|
| Constant | 0.43306113 |
| Std Err of Y Est | 6.89818445 |
| R Squared | 0.07722025 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.00100950 |
| Std Err of Coef. | 0.00024255 |

$PB_A = a_0 + a_1 \ln(PB_T)$

| Regression Output: | |
|---|---|
| Constant | -14.820143 |
| Std Err of Y Est | 6.58871399 |
| R Squared | 0.15615960 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 3.11307990 |
| Std Err of Coef. | 0.49919725 |

$PB_A = a_0 + a_1 PB_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | -1.4746949 |
| Std Err of Y Est | 6.69055893 |
| R Squared | 0.13193299 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.15996134 |
| Std Err of Coef. | 0.02851870 |

$\ln(PB_A) = a_0 + a_1 \ln(PB_T)$

| Regression Output: | |
|---|---|
| Constant | -7.0276499 |
| Std Err of Y Est | 0.77917859 |
| R Squared | 0.55560801 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.94971842 |
| Std Err of Coef. | 0.05903486 |

$PB_A = a_0 + a_1 PB_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -4.2378602 |
| Std Err of Y Est | 6.62701884 |
| R Squared | 0.14834272 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.89544940 |
| Std Err of Coef. | 0.14912662 |

$PB_W = a_0 + a_1 PB_T$

| Regression Output: | |
|---|---|
| Constant | 0.08291346 |
| Std Err of Y Est | 0.23017815 |
| R Squared | 0.06922140 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.00003175 |
| Std Err of Coef. | 0.00000809 |

$PB_A = a_0 + a_1 PB_T + a_2 PB_T^{(1/2)} + a_3 PB_T^{(1/3)}$

| Regression Output: | | | |
|---|---|---|---|
| Constant | 22.3367626 | | |
| Std Err of Y Est | 6.33752203 | | |
| R Squared | 0.22865098 | | |
| No. of Observations | 209 | | |
| Degrees of Freedom | 205 | | |
| X Coefficient(s) | -0.0121416 | 4.86999748 | -13.276657 |
| Std Err of Coef. | 0.00315069 | 1.22291117 | 4.59669982 |

$PB_W = a_0 + a_1 PB_T^{(1/2)}$

| Regression Output: | |
|---|---|
| Constant | 0.02895323 |
| Std Err of Y Est | 0.22633091 |
| R Squared | 0.10007581 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |
| X Coefficient(s) | 0.00462868 |
| Std Err of Coef. | 0.00096474 |

## REGRESSION ANALYSIS FOR LEAD SAMPLES (CONTINUED)

$PB_W = a_0 + a_1 PB_T^{(1/3)}$

| Regression Output: | |
|---|---|
| Constant | -0.0443370 |
| Std Err of Y Est | 0.22599956 |
| R Squared | 0.10270881 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |

| | |
|---|---|
| X Coefficient(s) | 0.02475522 |
| Std Err of Coef. | 0.00508562 |

$\ln(PB_W) = a_0 + a_1 \ln(PB_T)$

| Regression Output: | |
|---|---|
| Constant | -3.1365543 |
| Std Err of Y Est | 0.37674641 |
| R Squared | 0.07444731 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |

| | |
|---|---|
| X Coefficient(s) | 0.11647420 |
| Std Err of Coef. | 0.02854438 |

$PB_W = a_0 + a_1 PB_T + a_2 PB_T^{(1/2)} + a_3 PB_T^{(1/3)}$

| Regression Output: | | | |
|---|---|---|---|
| Constant | 1.77912594 | | |
| Std Err of Y Est | 0.20859505 | | |
| R Squared | 0.24297587 | | |
| No. of Observations | 209 | | |
| Degrees of Freedom | 205 | | |
| X Coefficient(s) | -0.0006386 | 0.24207094 | -0.8673466 |
| Std Err of Coef. | 0.00010370 | 0.04025125 | 0.15129712 |

$PB_A = a_0 + a_1 PB_W$

| Regression Output: | | |
|---|---|---|
| Constant | 0.80064462 | |
| Std Err of Y Est | 7.17454682 | |
| R Squared | 0.00180038 | |
| No. of Observations | 209 | |
| Degrees of Freedom | 207 | |
| X Coefficient(s) | 1.27710833 | |
| Std Err of Coef. | 2.09010638 | |

$PB_W = a_0 + a_1 \ln(PB_T)$

| Regression Output: | |
|---|---|
| Constant | -0.2989114 |
| Std Err of Y Est | 0.22744031 |
| R Squared | 0.09123186 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |

| | |
|---|---|
| X Coefficient(s) | 0.07855446 |
| Std Err of Coef. | 0.01723213 |

$\ln(PB_A) = a_0 + a_1 \ln(PB_W)$

| Regression Output: | |
|---|---|
| Constant | -0.1854435 |
| Std Err of Y Est | 1.12605070 |
| R Squared | 0.07187156 |
| No. of Observations | 209 |
| Degrees of Freedom | 207 |

| | |
|---|---|
| X Coefficient(s) | 0.80017301 |
| Std Err of Coef. | 0.19985923 |

# APPENDIX B

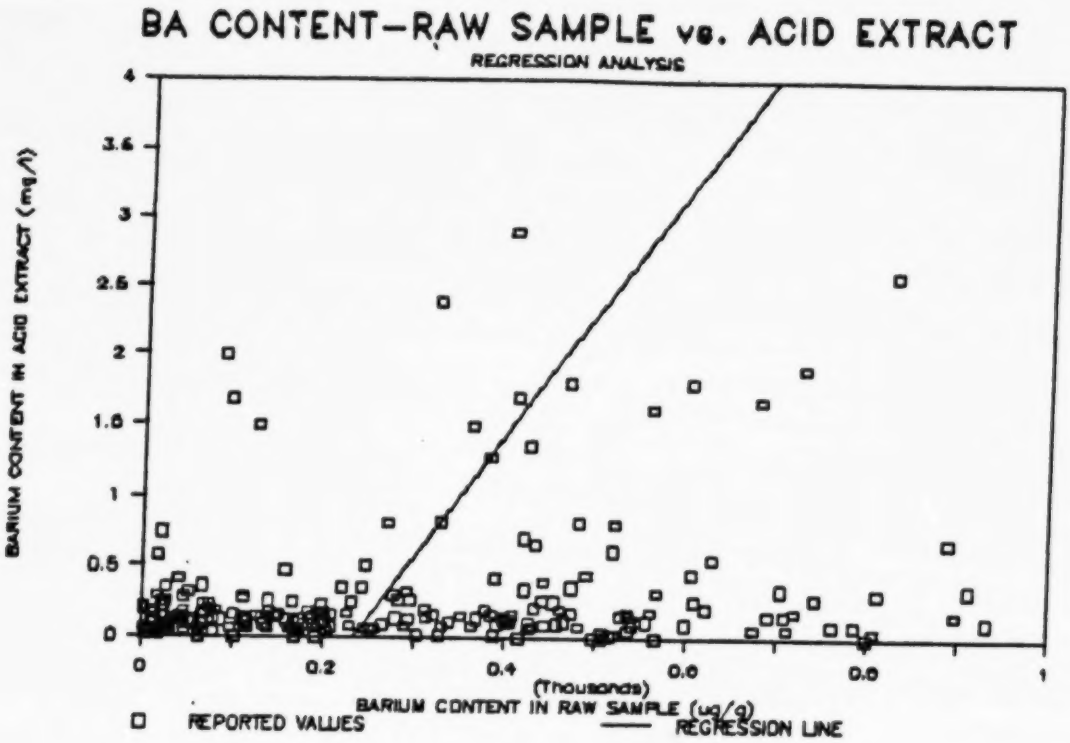


FIGURE 1

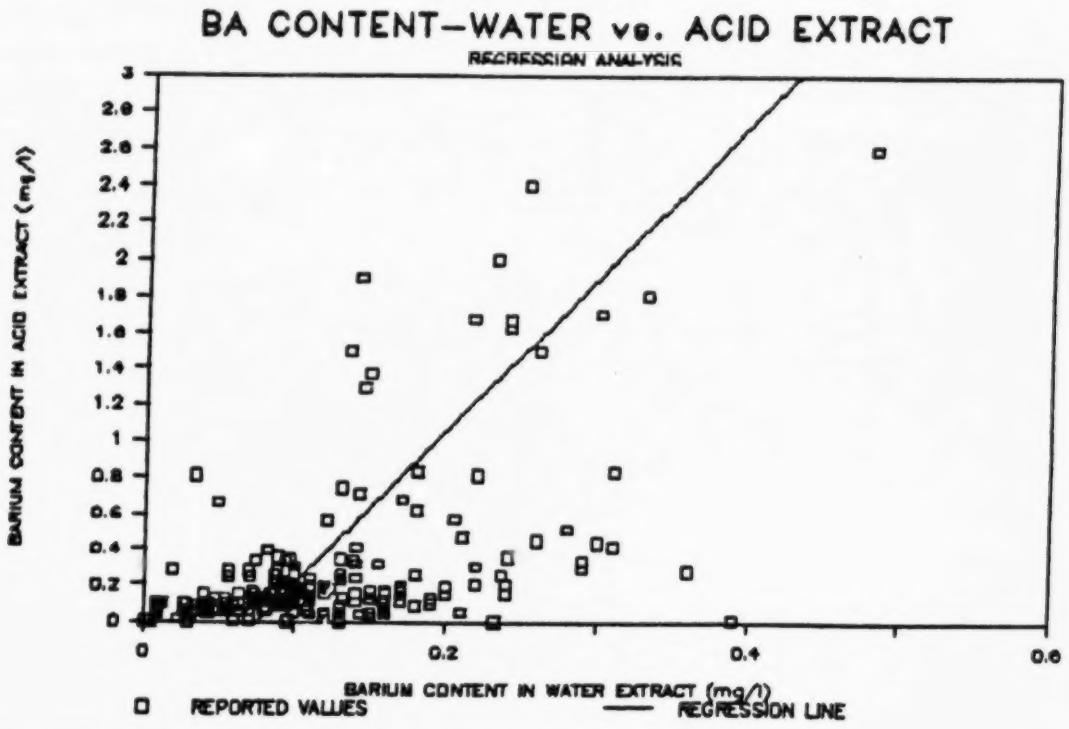


FIGURE 2

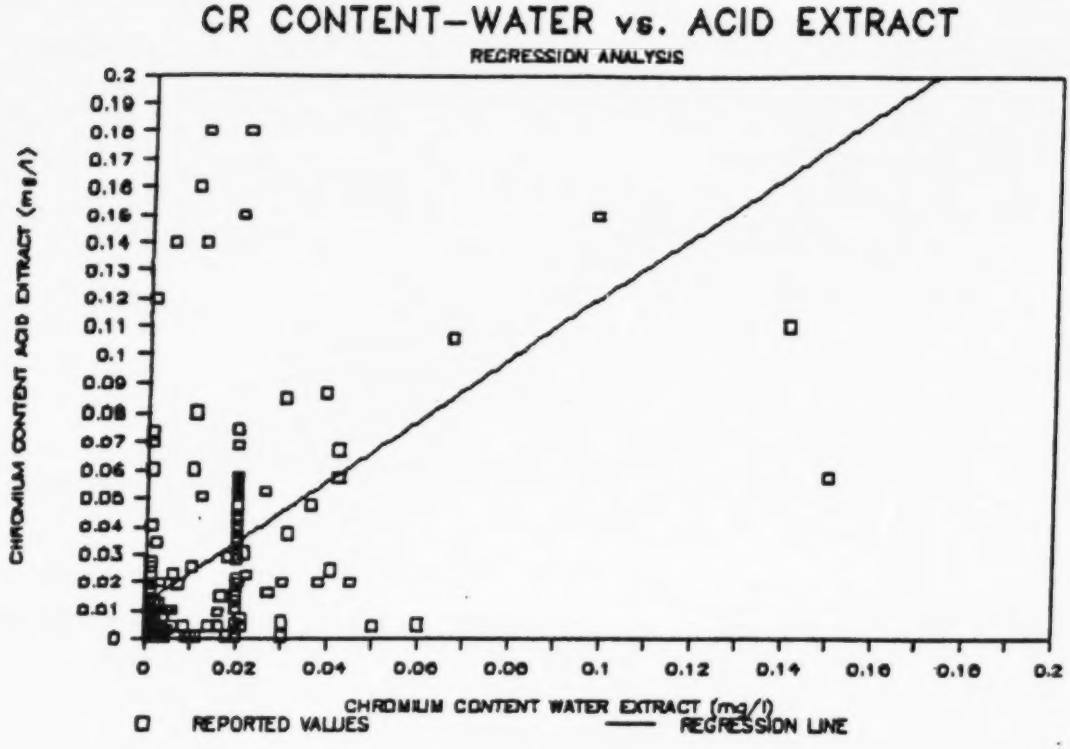


FIGURE 3

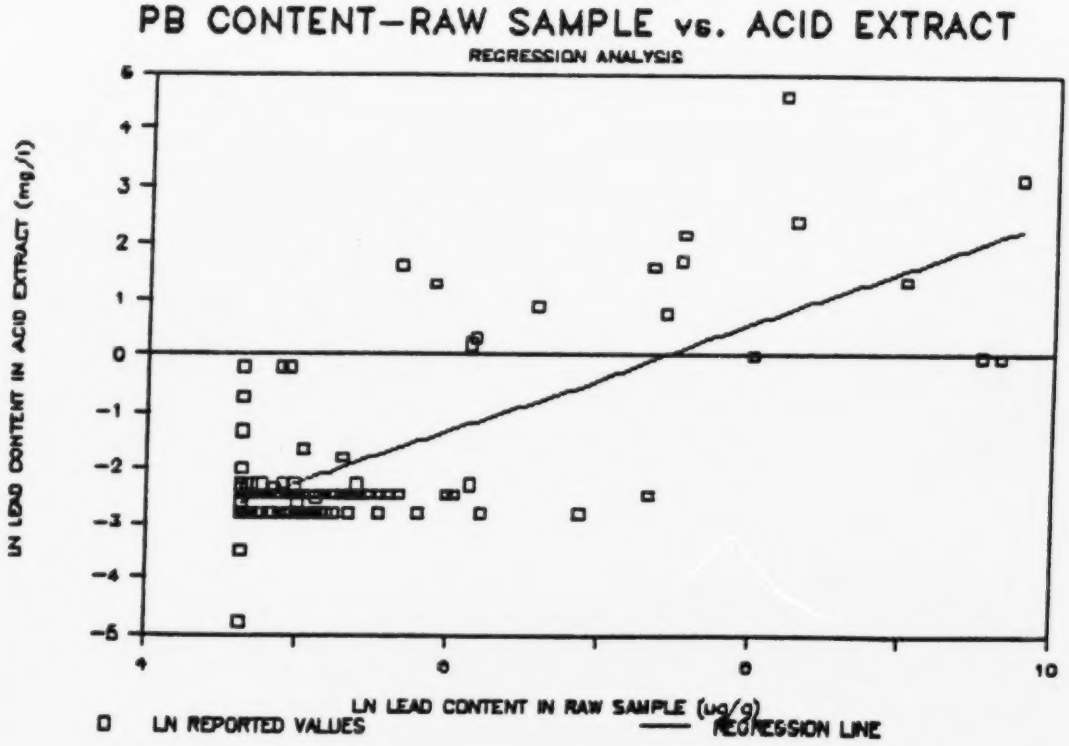


FIGURE 4